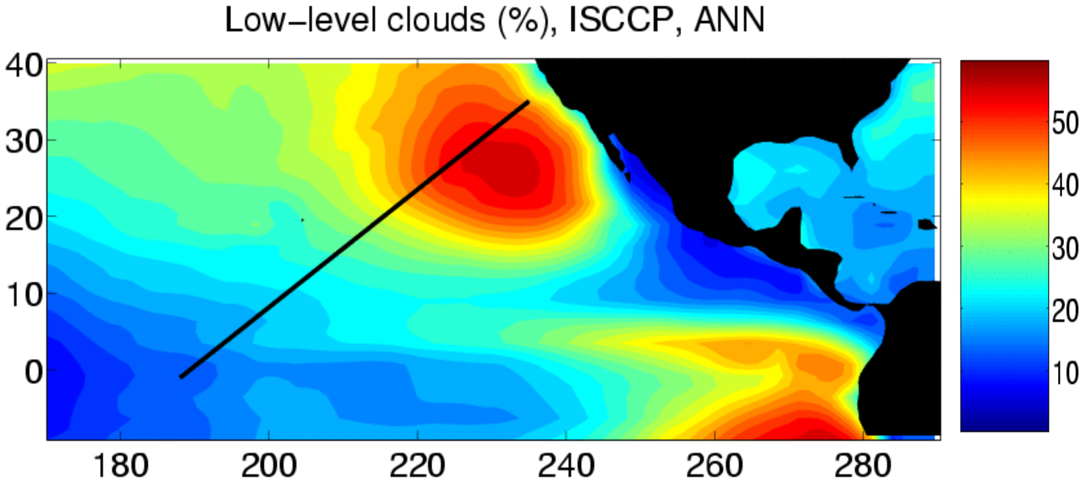
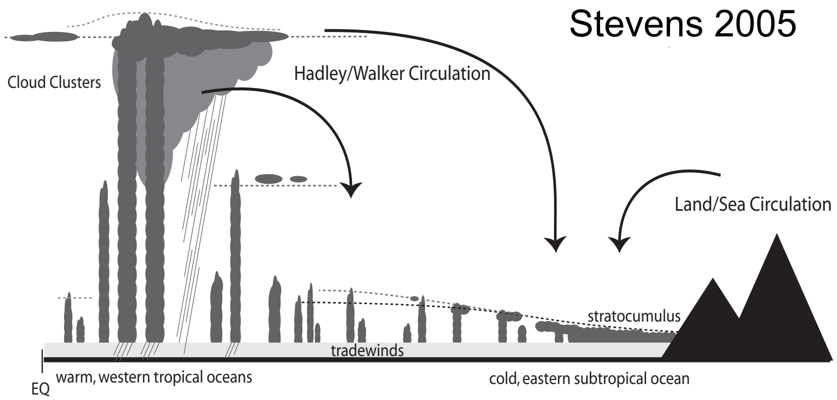
# Stratocumulus to Cumulus Transition CPT

## Chris Bretherton (UW) and Joao Teixeira (JPL)

**Goal**: Improve the representation of the cloudy boundary layer in NCEP GFS and NCAR CAM5 with a focus on the subtropical stratocumulus to cumulus (Sc-Cu) transition

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# Motivations for CPT

## NCEP

- Vision:  Can GFS become a unified operational weather-climate model for daily to interannual forecasting & reanalysis?
- Diagnose and improve clouds in operational GFS
- Evaluate free-running coupled GFS with climate model metrics
- Use single-column GFS as testbed for new parameterization ideas (ShCu mods, pdf cloud fraction, EDMF turbulence)

## NCAR

- CESM/CAM5 has new moist physics & aerosol parameterizations that change cloud climatology & feedbacks
- Their interaction is inadequately understood and suboptimal; CAM5 microphysics is complex, sensitive to model timestep

# CPT Current Main Tasks

a) Better coupled/uncoupled climate diagnostics for GFS
   (UCLA, NCEP, NCAR)

b) GASS Sc/Cu cases with NCAR and NCEP SCMs, and LES
   (UW, NCAR, NCEP, JPL)

c) Test SCM-suggested modifications in short coupled GFS runs
   (NCEP, UCLA, UW)

d) Development/testing of PDF cloud and new convection/ turbulence schemes in NCAR (LLNL, NCAR)

e) Development/testing of EDMF turb. param. in NCEP, NCAR
   (JPL, NCAR, UW, NCEP)

$$\overline{w'\varphi'} = -k\frac{\partial\overline{\varphi}}{\partial z} + M(\varphi_u - \overline{\varphi})$$

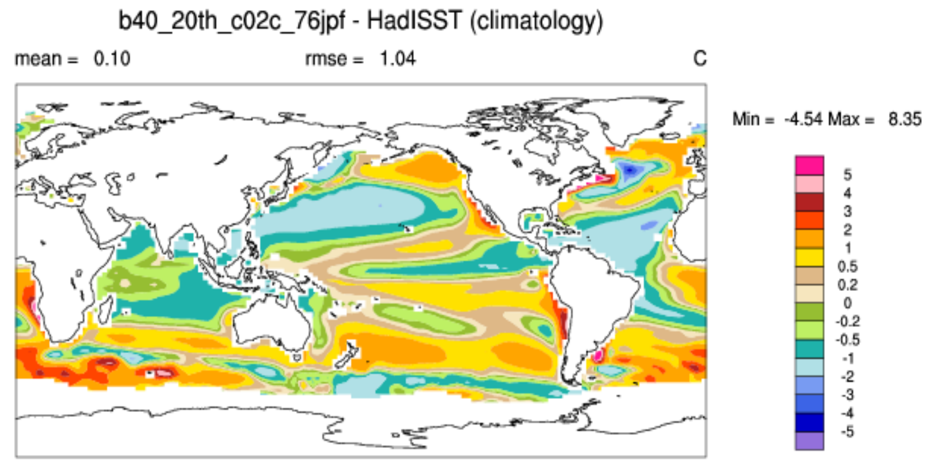
Siebesma & Teixeira, 2000

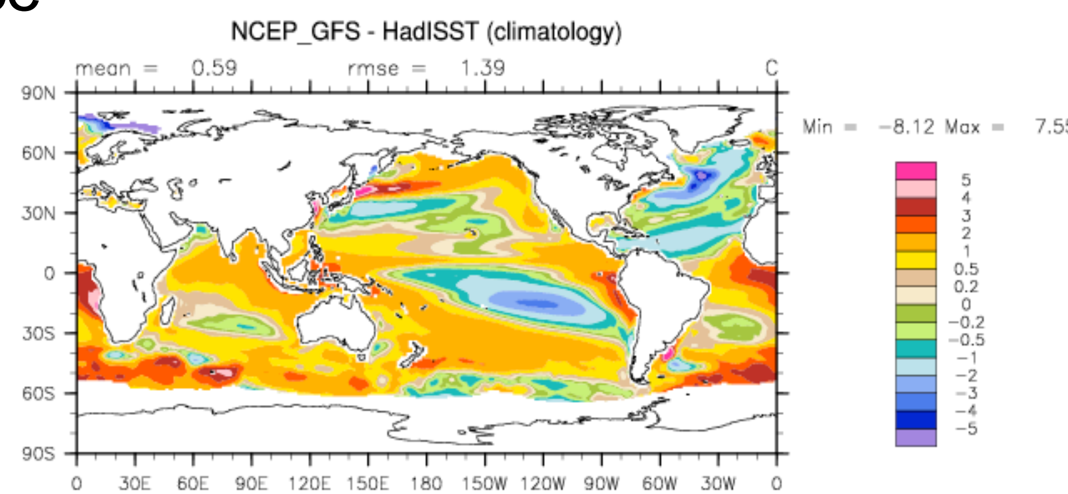
# Comparison of NCAR CESM1 and NCEP GFS

| Model | NCAR CESM1 | NCEP GFS |
|---|---|---|
| Atmosphere | CAM5 (2x2.5, L30) | GFS (T126 L64) |
| Boundary Layer Turbulence | Bretherton-Park (09)<br>UW Moist Turbulence | Han and Pan (11) |
| Shallow Convection | Park-Bretherton (09)<br>UW Shallow Convection | Han and Pan (11) |
| Deep Convection | Zhang-McFarlane<br>Neale et al.(08)<br>Richter-Rasch (08) | Han and Pan (11) |
| Cloud Macrophysics | Park-Bretherton-Rasch (10)<br>UW Cloud Macrophysics | Zhao and Carr (97) |
| Stratiform Microphysics | Morrison and Gettelman (08)<br>*Double Moment* | Zhao and Carr (97) |
| Radiation / Optics | RRTMG<br>Iacono et al.(08) / Mitchell (08) | RRTM |
| Aerosols | Modal Aerosol Model (MAM)<br>Liu & Ghan (2009) | Climatology |
| Dynamics | Finite Volume | Spectral |
| Ocean | POP2.2 | MOM4 |
| Land | CLM4 | NOAH |
| Sea Ice | CICE | MOM4 |

# NCEP Model Diagnostics (Xiao, Sun, Park)

- NCAR CESM 1.0 (coupled version of CAM 5.0, 200-yr run)
- NCEP GFS (coupled to MOM ocean model, 50-yr)
- NCAR AMWG diagnostic package adapted to GFS output
- Both models skillfully reproduce global circulation patterns.
- GFS avoids double-ITCZ bias.



# 50 yr C-GFS vs. 100 yr CESM1 climo: AMWG metrics

| cor coef: Space-Time | cam3_5_fv1.9x2.5 | b40_20th_c02c_76jpf | NCEP_GFS |
|---|---|---|---|
| | ANN | ANN | ANN |
| Sea Level Pressure (ERA40) | 0.949 | 0.959 | 0.956 |
| SW Cloud Forcing (CERES2) | 0.707 | 0.714 | 0.408 |
| LW Cloud Forcing (CERES2) | 0.820 | 0.769 | 0.781 |
| Land Rainfall (30N-30S, GPCP) | 0.785 | 0.811 | 0.751 |
| Ocean Rainfall (30N-30S, GPCP) | 0.802 | 0.757 | 0.733 |
| Land 2-m Temperature (Willmott) | 0.876 | 0.876 | 0.911 |
| Pacific Surface Stress (5N-5S,ERS) | 0.872 | 0.797 | 0.834 |
| Zonal Wind (300mb, ERA40) | 0.967 | 0.960 | 0.957 |
| Relative Humidity (ERA40) | 0.900 | 0.874 | 0.906 |
| Temperature (ERA40) | 0.912 | 0.932 | 0.984 |

C-GFS pattern correlations better than CESM1 for

Pac surface stress, land surface temperature, 3D T/RH, but worse for

shortwave cloud forcing, rainfall.

Overall, C-GFS climatology is remarkably good for a weather-tuned model.

# GFS Problem Area 1: Global energy budget

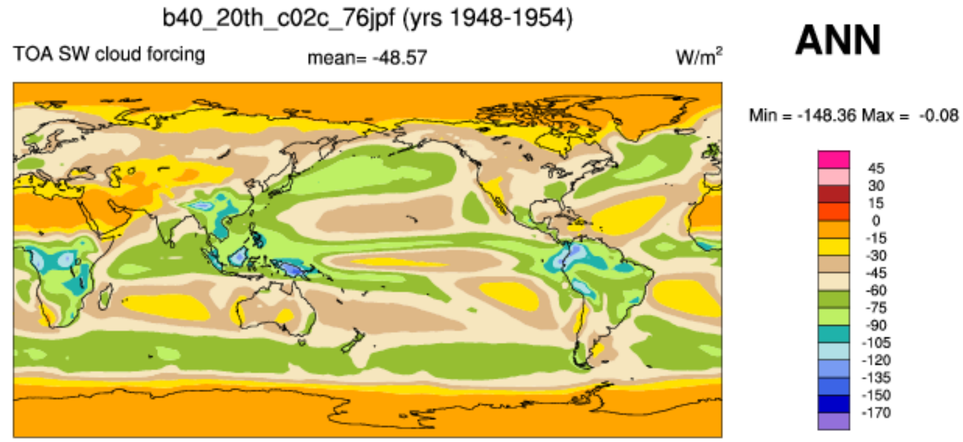
| $[W\ m^{-2}]$ | GFS | NCAR | CERES2 |
|---|---|---|---|
| TOA $F_{net}$ | 9.0 | -0.2 | 0.8 |
| TOA-surf $\Delta F_{net}$ | 4.3 | 0.0 | |
| TOA $SW_{net}$ | 259 | 238 | 240 |
| TOA $SW_{clr}$ | 284 | 287 | 287 |
| SWCRF | -25 | -49 | -47 |
| TOA $LW_{net}$ | 250 | 238 | 240 |
| TOA $LW_{clr}$ | 268 | 260 | 269 |
| LWCRF | 18 | 22 | 30 |

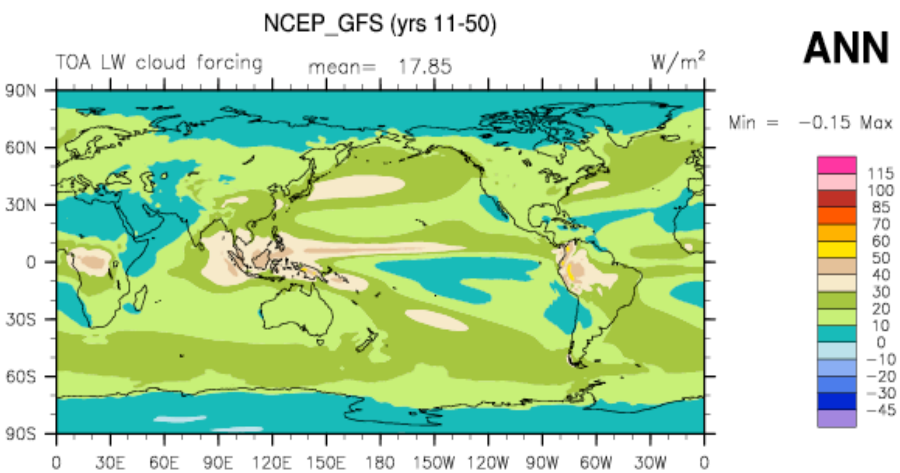
Two large compensating biases in GFS:

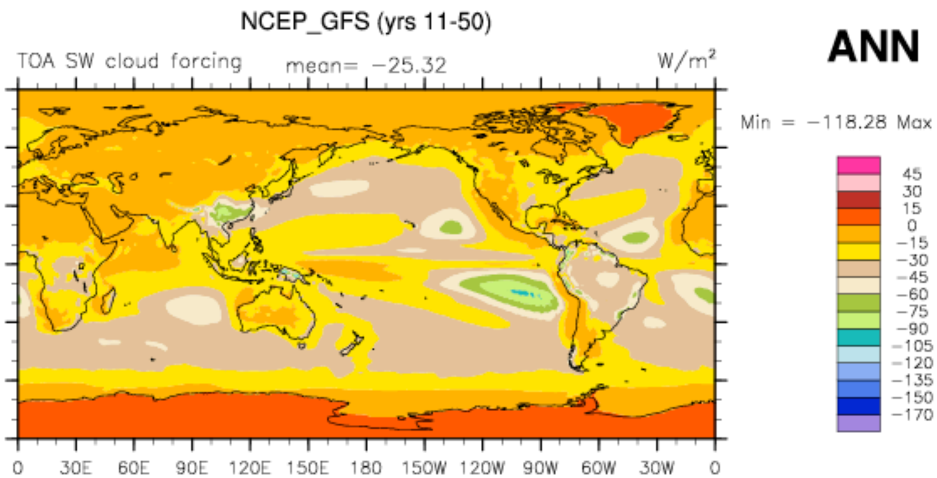
- Net spurious energy loss in atmosphere [and ocean?]
- Shortwave, longwave CRF are 40-50% too low, allowing in 10 $W\ m^{-2}$ too much net radiation.

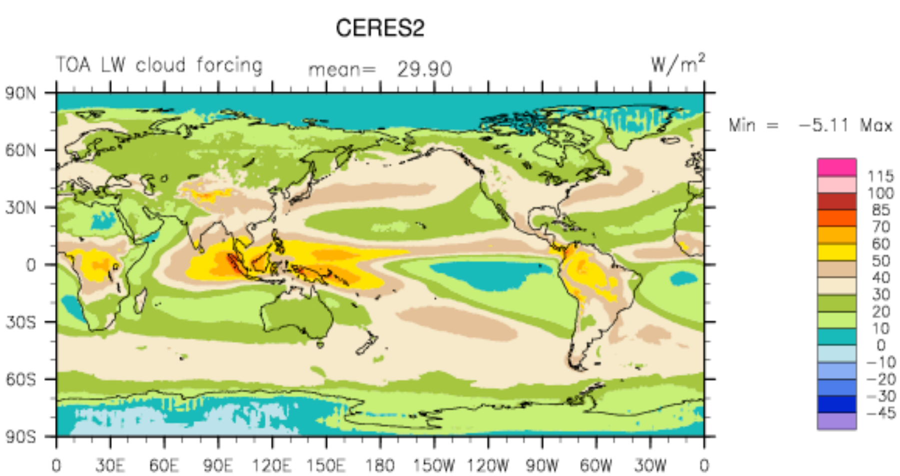
# GFS problem area 2

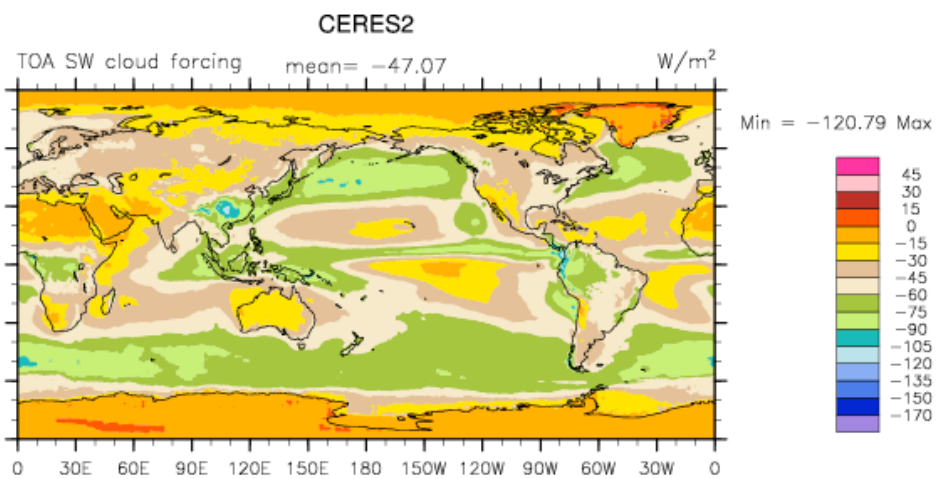
Big low bias in GFS cloud radiative forcing, esp. regions of deep high cloud. Subtrop. Sc too far offshore



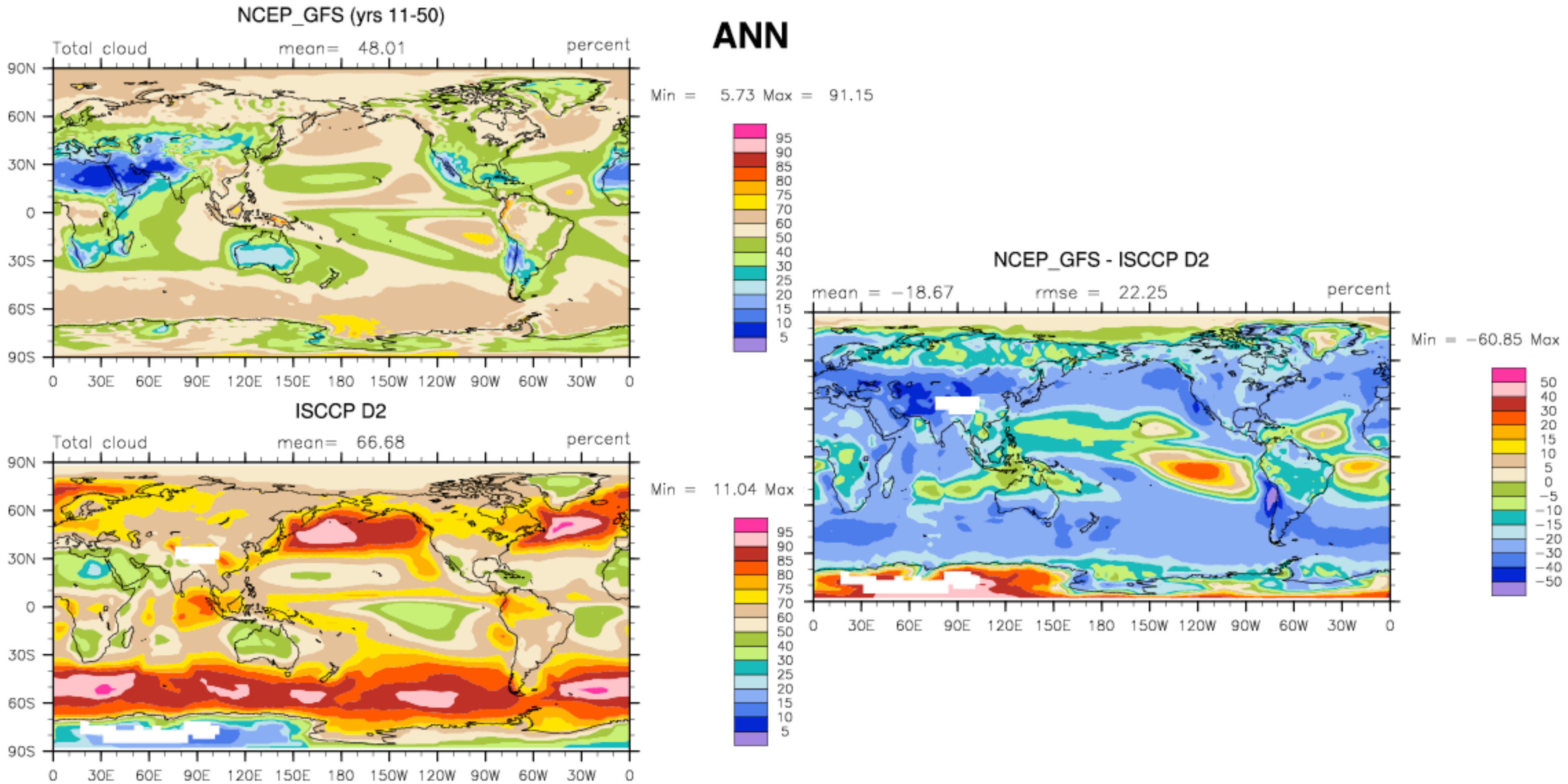



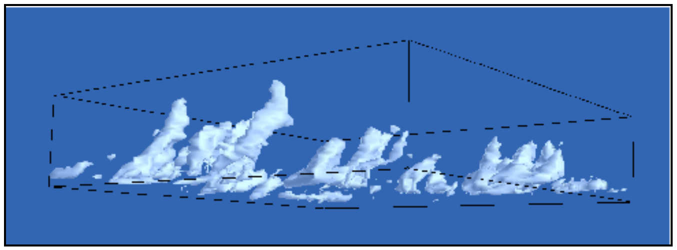
# Main culprit:  Too little cloud cover in GFS




Microphysics?

Cloud fraction scheme?

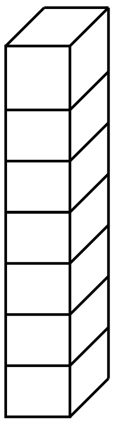
# Single-column testing and improvement of GFS

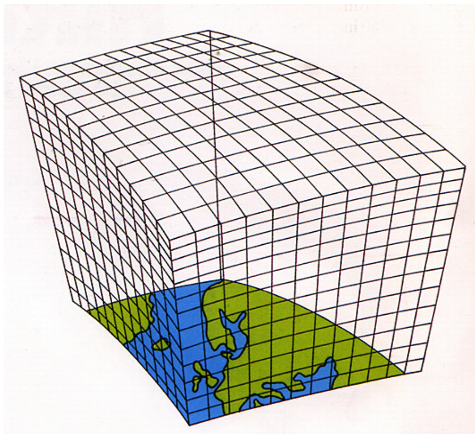


High-resolution model data:

Large Eddy Simulation (LES) models

Cloud Resolving Models (CRMs)





Testing in Single Column Models:

Versions of Climate Models

3D Climate/Weather Models:

Evaluation and Diagnostics with satellite observations

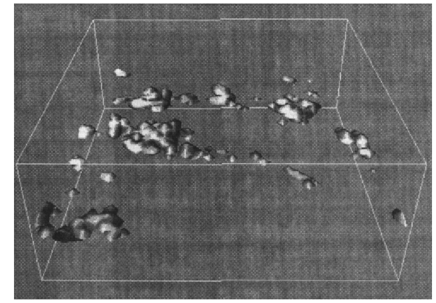
LES/CRM models provide unique information on small-scale statistics

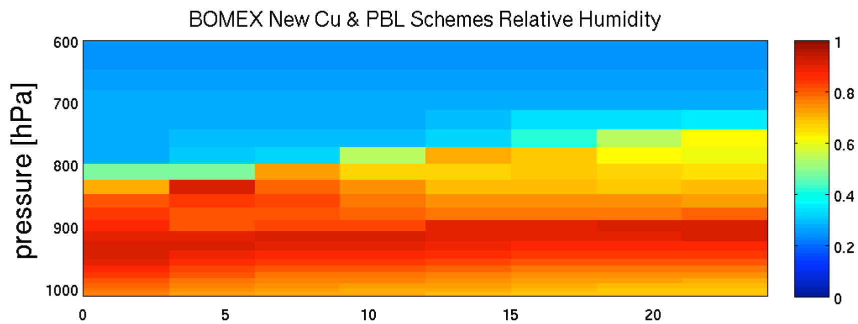
# Single-column modeling with GFS (Fletcher, Han, Sun, Blossey)

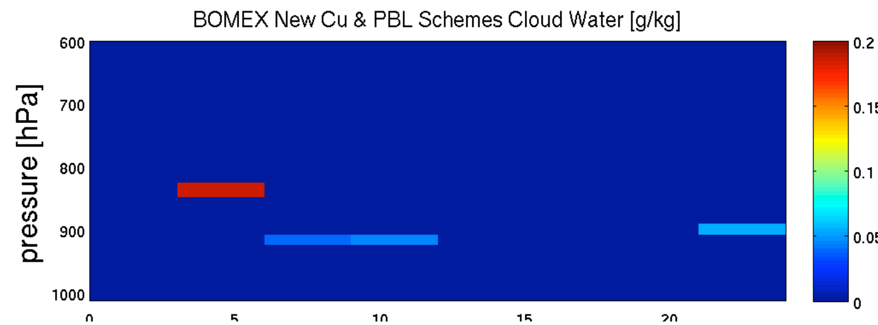
- Single-column GFS existed (pre-2010 physics) but not run outside NCEP, nor on intercomparison cases
- Technical issues:
  - Lack of GFS documentation or useful commenting
  - Code inflexible to changes in forcings, physics, outputs
  - Default outputs inadequate to diagnose parameterizations
- With effort, SC-GFS runs at UW with new physics and has been adapted to three GCSS cases (Sc, shallow Cu, Sc-Cu transition) for which LES and some observational comparisons exist.
- Results suggest simple model improvements that we have begun to test in both single-column and global coupled mode.

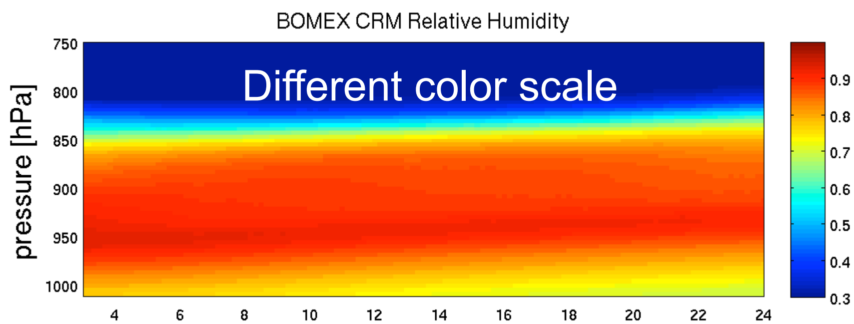
# BOMEX nonprecipitating trade Cu case

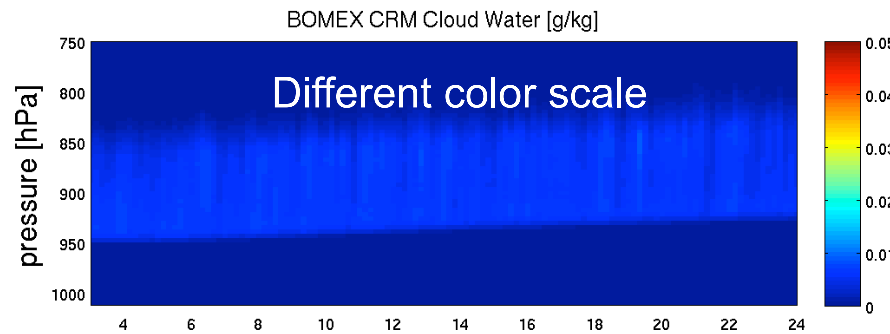
Siebesma et al. 2003



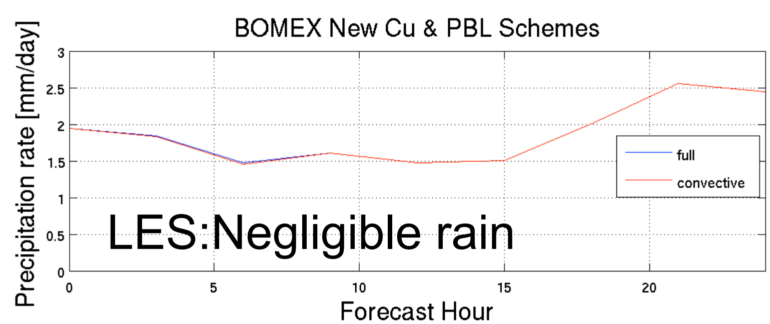


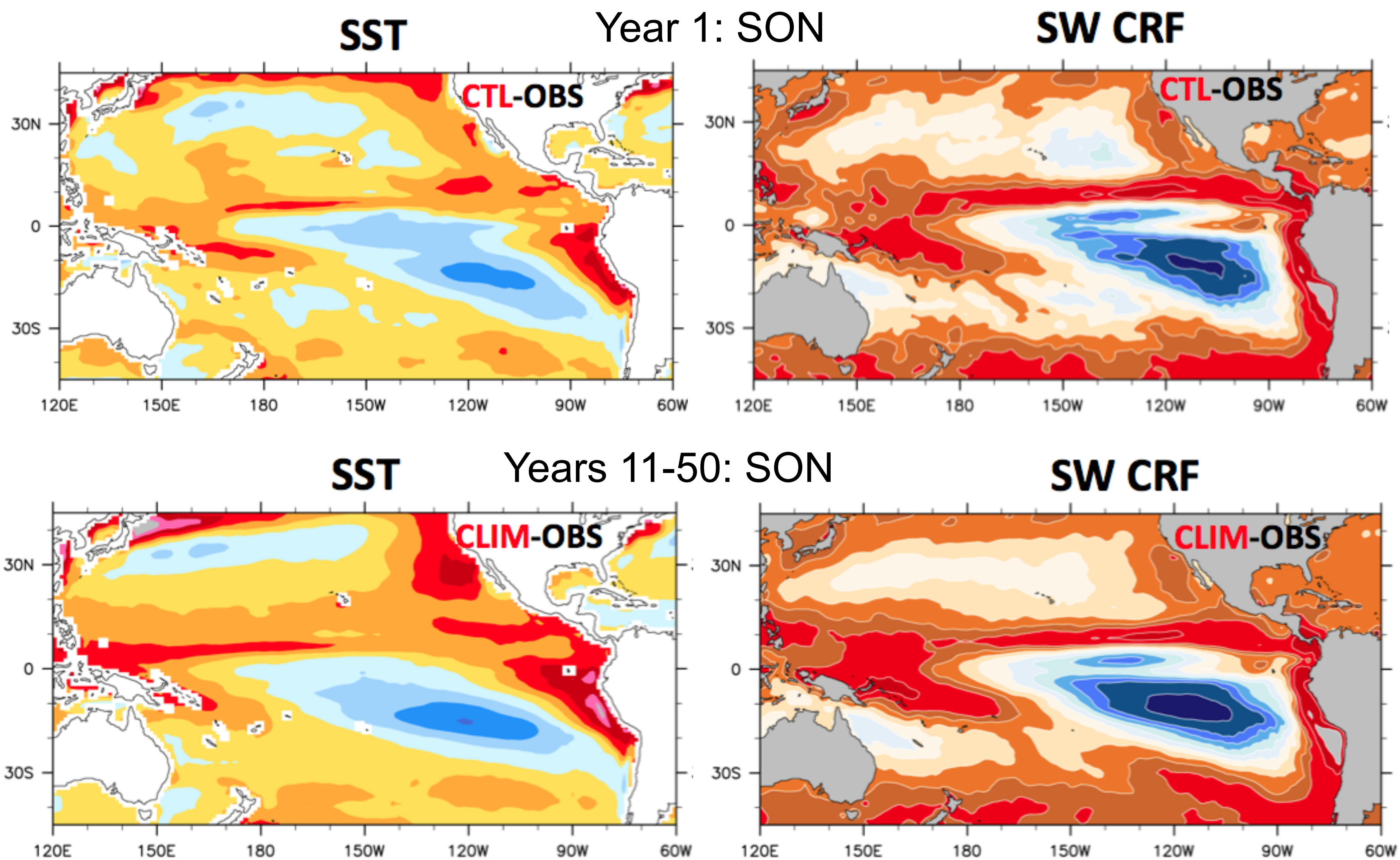




- Too much rain. From LES: Raise lateral entrainment 3x, decrease precip efficiency 2x.
- Cu cloud cover problematic



# 1 year coupled GFS sensitivity runs (Sun, Han, Xiao)

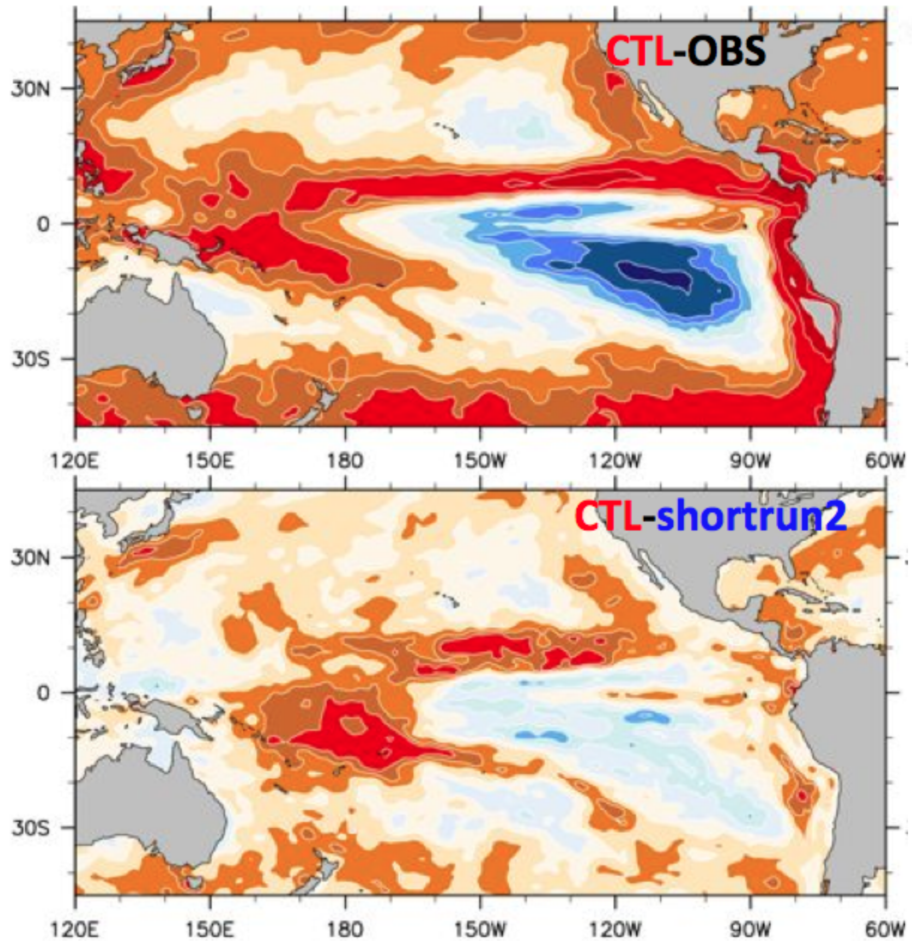
- Tropical cloud/SST biases in coupled model develop fast



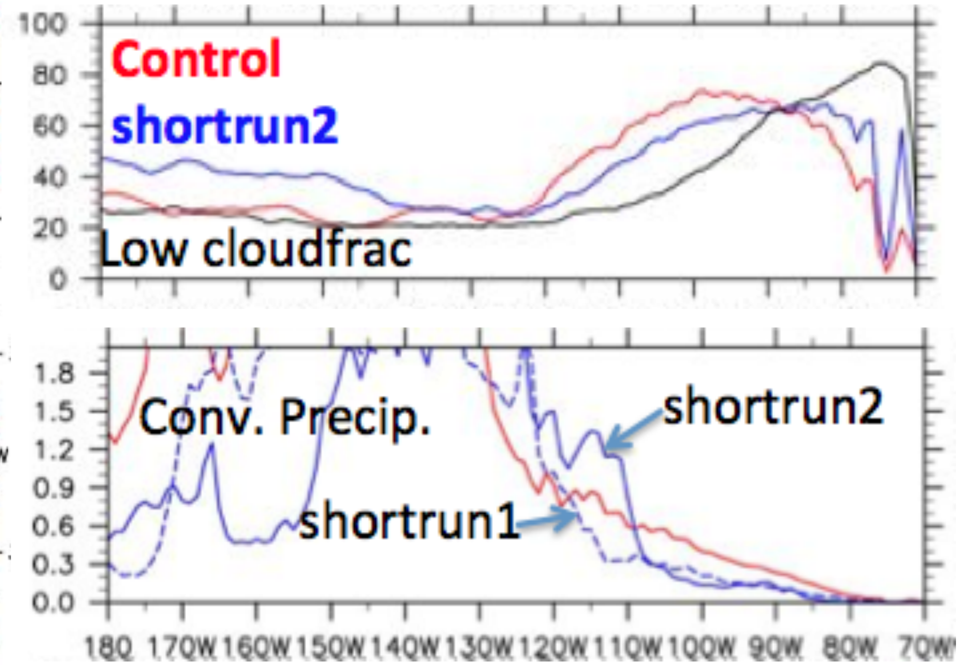
# Sensitivity to ShCu changes (shortrun2)

SON Year 1

ΔSWCRF




20S x-sections




- ✓ Increase in trade Cu cloud
- ✓ Decrease in ShCu rain
- ✓ Shift of Sc toward coast
- ✓ SWCF improvement

# TKE dissipation heating (Han)

$$\varepsilon = \underbrace{-K_h \frac{g}{\theta_v} \frac{d\theta_v}{dz}}_{\text{buoyancy production}} + \underbrace{K_m \left| \frac{d\mathbf{u}}{dz} \right|^2}_{\text{shear production}}$$

| 4 month coupled GFS runs | TOA ($W/m^2$) | SFC ($W/m^2$) | Difference ($W/m^2$) |
|---|---|---|---|
| CTL | 16.2 | 9.6 | 6.6 |
| EXP1: same as shortrun2 in Heng (dissipative heating only at the model first layer) | 7.9 | 5.1 | 2.8 |
| EXP2: same EXP1 but w/o dissipative heating | 8.2 | 2.3 | 5.9 |
| EXP3: same as EXP1 but w/ dissipative heating over whole atmospheric layer | 7.8 | 6.9 | 0.9 |

…atmospheric energy loss is now much smaller.

# Summary

1. New global climate diagnostics for CGFS:
- Many fields as good or better than CESM1 climate model
- Cloud rad forcing much too weak, biasing climate warm
- GFS energy leaks compensate this bias
2. GASS single-column cases test GFS physics
- Shallow Cu entrain too little, precipitate too much
3. Short coupled runs
- Fixing ShCu issues improves global coupled simulation
- Atm. energy leak fixed by adding dissipative heating.

CPT goals for next year:
- Improve microphysics to increase deep cloud
- Improve Sc entrainment formulation to enhance coastal Sc
- Test EDMF turb. for cloud-topped boundary layers.